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A review of the application of acoustic emission techniques for monitoring forming and grinding processes

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Abstract

Application of acoustic emission technique (AET) for on-line monitoring of various forming processes such as punch stretching, drawing, blanking, forging, machining and grinding has been reviewed and discussed in this paper. Acoustic emission (AE) generated during the forming processes gives useful information for detecting die wear and cracking, friction properties, state of lubrication, galling, stick-slip, etc. AE monitoring of open die and closed die forging of Al alloys has shown that AET can be used to monitor industrial forging processes.

Keywords: Metal forming; Acoustic emission technique; Punch stretching; Drawing; Blanking; Forging; Machining; Grinding

1. Introduction

Accurate microstructure evolution models for materials and process models for various forming and grinding operations are important for controlling microstructural development in a product. Computer aided design based procedures are adopted for modelling deformation mechanisms as well as mechanics of flow that occur during the forming processes. Modelling of materials processing becomes important since the process parameters significantly influence the microstructural development in the component. Modelling of materials flow and proper die design are necessary to obtain reliable products, otherwise, improperly designed die profile leads to incomplete die filling, excessive load requirement, die breakage, folding, etc. For modelling materials flow in metal forming, finite element analysis is also widely used. Another significant progress being made in this direction is the adoption of intelligent processing of materials (IPM) which combines process models with the characteristic parameters of the process equipment for predicting the behaviour of materials and its final microstructural condition. The knowledge about the behaviour of materials together with process models that predict the response of the materials to the external stimuli (i.e. temperature, strain rate, etc.) are used to plan and execute the feedback control schemes to achieve the desired final microstructural condition.

In hot forming of metals, open-loop control methods are used for producing quality products. This open-loop control method uses empirical microstructure development models to determine the optimum deformation path for achieving the desired microstructure and a process model to calculate the processing parameters necessary for achieving the optimum deformation path. The required processing parameters are utilised to set-up and regulate the metal-working equipment used to produce the component. Feedback based improvements between the metal-working equipment and the process model are not considered in the open-loop control method. This open-loop control approach requires that the process model be very accurate in predicting all aspects of the deformation process or that the process model be empirically calibrated. The former is not computationally feasible, and the latter is difficult to achieve consistently. For this reason, real time feedback control with appropriate process monitoring or sensing methods is needed for ensuring products with desired microstructural condition.

Application of nondestructive evaluation (NDE) sensors can play a significant role in real time monitoring of various forming processes. Fig. 1 depicts how a NDE sensor can be used in a closed-loop feedback system to monitor and control a manufacturing process [1]. Such an approach is followed in IPM. Closed-loop control can be conveniently divided into three components: sensor, process model and actuation. The sensors can be of different types. Ideally, they would be directly sensitive to the property of the material desired to be controlled, e.g. a thickness gauge based on ultrasonics. The process model defines the relationship

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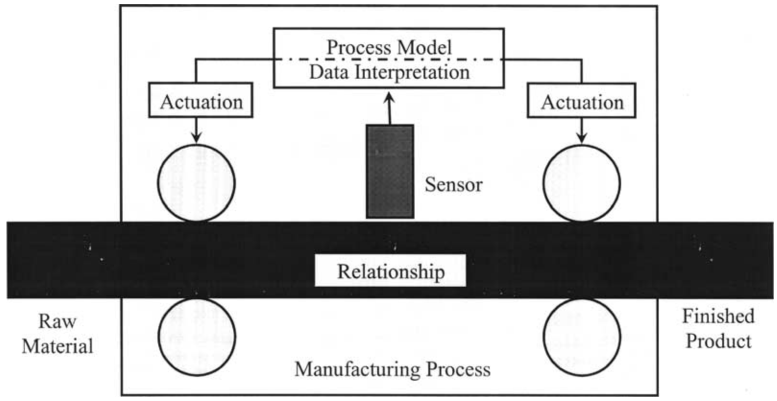

Fig. 1. Schematic diagram showing NDE sensor in a closed-loop feedback system to monitor and control a manufacturing process [1].

between the sensed parameter, the desired material property and the process variables. Actuation is concerned with effecting the necessary variations in the process parameters. Assuming that the model generates a suitable control signal as a result of input data from the sensors, this signal must actuate changes in the process. In the case of a rolling mill, it could be used to change the separation or speed of the rollers.

Acoustic emission technique (AET) is one of the important and advanced nondestructive evaluation tools that has the capabilities for real time process monitoring applications. A transducer or sensor acoustically coupled to a sample undergoing dynamic changes, detects the elastic (acoustic) energy emitted by the sample and gives information about the dynamic changes taking place in the sample. AET has been used extensively to study various deformation and welding processes in different materials [2,3].

The characteristics of the acoustic emission (AE) signals generated during forming processes depend on the properties of the workpiece material (hardness, strength, toughness, etc.), the experimental conditions (strain rate, temperature, lubrication, etc.) and the nature of the AE source mechanisms (plastic deformation, fracture, friction, etc.). The use of AET for process monitoring enables ensuring a high quality product while minimising the total cost of the product. The AE generated during forming processes can be monitored to characterise the processes and also to detect discontinuities or process abnormalities in situ.

In this paper, an overview of the application of AET for on-line monitoring of various forming and grinding processes such as punch stretching, drawing, blanking, forging and grinding are discussed. Punch stretching, deep-drawing and cup-drawing are important sheet metal forming processes. Numerical analyses and modelling are usually performed to predict states of these processes. On-line monitoring of these processes by AET can yield in-depth information regarding various stages of the sheet metal forming processes with respect to initial contact of the punch with the workpiece, plastic deformation and fracture. A few works on AE monitoring of sheet metal forming processes like punch stretching, deep-drawing and cup-drawing have been reported in published literature [4–9].

The occurrence of friction between tool and working material in sheet metal forming process can be detected by recording AE signals during the process and information obtained from such studies could be used to assess the state of lubrication and in turn the product quality.

Acoustic emission generated during contact friction in deep-drawing processes has been studied and it has been shown that increased contact between two mating surfaces and increased relative speed of the surfaces result in increased AE [10,11]. Blanking is one of the important and most rapid operations of metal forming. The process of blanking is affected by the characteristics of punch/die, material properties and process variables. Usually force–displacement signals are used to monitor and control blanking processes but, often, complexity of signals and difficulty of interpretation do not yield desirable results. In such a situation, neural networks created using inputs extracted from AE signals and force measurements, could predict blanking parameters with sufficient degree of accuracy [12,13].

Abrasive flow machining (AFM) is a nontraditional finishing process that works by forcing an abrasive-laden viscoelastic polymer across the workpiece surface. Applications of AET for monitoring abrasive flow machining have been reported [14,15].

Forging is another important metal forming process used extensively in industries. AE monitoring of forging process has been reported [16]. In this investigation, models of AE event rate have been developed for upset forging and disk forming operations [16]. The effect of friction factor on the AE signals for a simple upsetting process has been also studied [16].

In the following sections, the above-mentioned applications of AET are discussed in detail. A programme has been initiated by the authors to investigate the industrial forging process using AET, in collaboration with Hindustan Aeronautics Ltd. (HAL), Bangalore. In the last section of this paper, salient features of the results obtained from this programme are also presented.